Galaxy Environments with the Far-Infrared Surveyor

Science aim: Understand the role of environment on galaxy evolution by mapping dust-obscured galaxies onto the cosmic web**.**

Scientific Importance Environments on scales of up to about 10 Mpc play a crucial role in regulating the assembly of galaxies. This is demonstrated by, for example, the strong differential clustering of galaxies as a function of luminosity, and the rapid growth of galaxies in dense environments. Moreover, the *shape* of environment that galaxies reside in - clusters, filaments, sheets, and voids - is now established as just as much a driver of galaxy assembly as is galaxy density itself. Finally, galactic environments offer the exciting opportunity to constrain the assembly history of the underlying dark matter haloes, by studying e.g. the conformity in galaxy properties on cluster and supercluster length scales. Motivated by this, many recent and current surveys have studied galaxy environments, from the optical to the radio, and several upcoming surveys are scheduled to do so, in particular DES, WFIRST, and SKA.

Studies of galaxy environments have three core requirements; i) they must sample an adequate volume to have *multiple* cells on the largest scales of interest, out to z=2; ii) they must be deep enough to sample well into the bulk of the galaxy population across 0<z<2; and iii) they must observe at wavelengths that trace all of the key phases in galaxy assembly within that volume. This however means that *all existing or planned extragalactic surveys lack one or more of these requirements*; optical surveys almost entirely miss the obscured phases of galaxy assembly that dominate the comoving luminosity density at z>1, while radio surveys may detect active systems, but cannot accurately characterize key properties such as SFRs and AGN luminosities that allow those galaxies to be set in context with the structures they reside within.

At the core of environment studies is the growth of galaxy clusters. Simulations suggest that massive clusters are seeded by small density perturbations at the recombination epoch, with a major growth phase from z~2 to z~0, as shown in Fig 1.

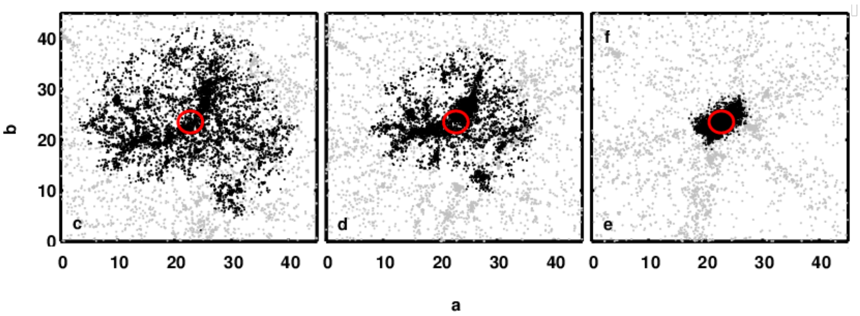

Fig 1: From Muldrew et al 2015 - the evolution in size of a $10^{15.4}$ M_{sun} (at z=0) cluster, shown at z=2, z=1, and z=0. Each box is 45 x 45Mpc. The red circle is the (eventual) cluster center. The progenitors of 10^{15} M_{sun} z=0 galaxy clusters stretch ~40 comoving Mpc across at z=2, which corresponds to ***~half degree scales*** *on the sky.*

Hence, the distribution of massive clusters as a function of redshift provides a powerful observational tracer of the growth of structure over the history of the Universe. However, standard approaches to find (proto) clusters at z>1 become ineffective; the red sequence has largely yet to form, while the intracluster gas is not yet hot enough to allow X-ray detections.

The Far-Infrared Surveyor will have a profound impact on studies of galaxy environments by having the spatial resolution and spectroscopic sampling to identify obscured, active galaxies in sufficient numbers, and with redshift information, that they can be mapped onto underlying structures in the cosmic web. This allows FIRS to assess the impact of environment on ongoing phases in galaxy assembly. An example is shown in Fig 2.

While the FIRS will perform ground-breaking studies of environments on its own, the greatest synergy will be with WFIRST, which will perform surveys with depth equivalent to the Hubble Deep Fields over several square degrees. The WFIRST surveys give a complete census of how *quiescent* galaxies trace Mpc scales, and how they are affected by their local environments. Moreover, WFIRST will also provide morphological information, allowing for the breaking of several degeneracies between morphology and environment drivers. FIRS and WFIRST together thus give a complete census of how active and quiescent galaxies are affected by environment, across the epoch where galaxy assembly is most rapid and where clusters experience the most rapid stage of collapse and growth.

Measurements Required 10 deg^2, split across 2-3 fields, to 1 dex below the knee of the LF at z=2 is a decent minimum. Ideal - 50+ deg^2 to 2+ dex below the knee of the LF - this gives synergy with e.g. the DES/LSST "Deep Drilling" fields, and with the equivalent deep SKA surveys. This assumes detections in 2-3 lines and 1+ continuum bands.

Longevity/Durability No existing or planned IR observatory gives synergy with WFIRST. Herschel and Spitzer did not have the resolution or sensitivity, while ground-based facilities cannot access the required diagnostic lines. JWST and ALMA cannot survey large enough areas. SKA surveys have the depth and area, but lack the ability to characterize the sources in an obscuration-independent way, instead relying on optical diagnostics.

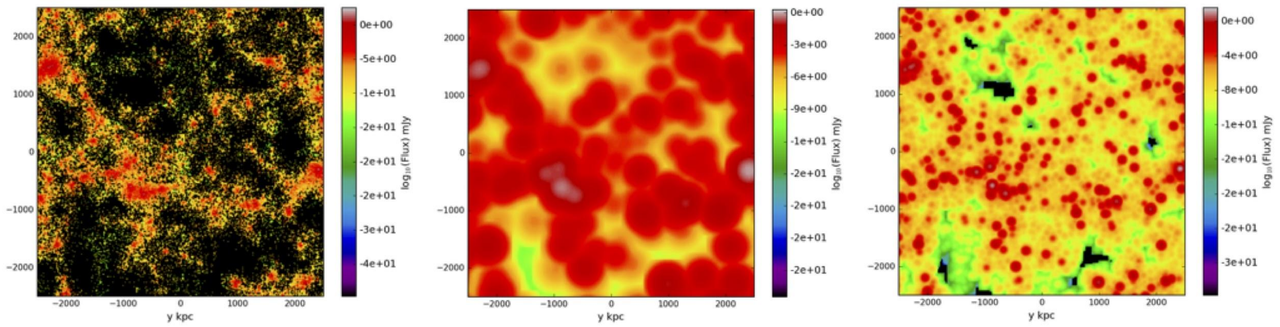

Fig 2: the left panel shows an n-body simulation of a 64 Mpc^3 volume at z=1, the middle panel shows how the volume would look to Herschel, while the right panel shows how the volume would look to a 15m FIRS. This demonstrates that while Herschel only picks up the densest nodes, FIRS obtains individual detections along the cosmic web. A FIRS also provides the spectroscopic redshifts that allow such structures to be fully characterized in three dimensions.

Performance Requirements

Parameter	Unit	Required value	Desired Value	Comments
Wavelength/band	microns	80 - 500	40 - 800	Req: 3-4 continuum bands over the rest-frame peak in the IR SED, plus a few bright lines for redshifts and source characterization, for sources up to z=2. Ideal: More continuum bands/lines improve source characterization
Number of targets		L*+1 at z=2	L*+2 at z=2	Enough sources for 2-point correlations, void and filament finders, etc. Max redshift is based on where environmental effects are thought to become significant.
Survey area	deg.^{2}	10 deg^2 in 3 fields	50 deg^2 in 4-6 fields	Req: Reduce CV systematics to <2% at z=2, and have enough cells to get <20% errors on ~cluster scales Ideal: Synergy with DES/LSST DDFs, better sensitivity to larger scales (up to several cluster lengths).
Angular resolution at 100 microns	arcsec	5”	<0.5”	Req: small enough PSF so that confusion does not curtail hurt too much (assumes we have spec-zs) Ideal: Compare far-IR and optical morphologies.
Spectral resolution	Dl/l	R=500	R=1000	Driver for resolution is accurate fine structure line redshifts, which doesn’t push to high values.
Spectral line sensitivity (1 sigma)	W m^{-2}	1e20 Wm^{-2}	1e21 Wm^{-2}	Req: Redshifts and basic source properties for 1x10^{11}L$_{sun}$ systems at z=2 - detect CII line fluxes of 5x10^{20} Wm^{-2} Ideal: below 5x10^{10} L$_{sun}$ at z=2